

# Excess of pions with chiral symmetry restoration \*

Chungsik Song and Volker Koch

Chiral symmetry, a symmetry of quantum chromodynamics (QCD) in the limit of massless quarks, is spontaneously broken in the ground state of QCD as indicated by the small mass of the pion. At high temperatures chiral symmetry is expected to be restored. However, some intriguing questions still remain on how chiral symmetry is actually restored in hot hadronic matter and what are the signatures of the restored phase.

One of the interesting features of the symmetry restored phase is the appearance of the scalar  $\sigma$ -meson which forms a chiral multiplet with the pions. At low temperatures where chiral symmetry is spontaneously broken, the  $\sigma$ -meson has very large width due to the strong decay channel into two pions. On the other hand, as the quark condensate drops with increasing temperature, the mass difference of the  $\sigma$ -meson and pion becomes small. As a result, the decay width of scalar meson decreases because the phase space available for the outgoing pions is reduced. Close to the phase transition temperature  $T_\chi$ , the  $\sigma$  becomes an elementary excitation.

The observation of a narrow width scalar meson has been suggested as a direct signature of chiral symmetry restoration [1], but since the  $\sigma$  does not couple to any penetrating probes such as photons and dileptons this is difficult to observe in experiment. The purpose of this paper is to study the effect of the  $\sigma$ -meson on the pion production in high energy nucleus-nucleus collisions.

The pion production will depend on the thermodynamic conditions of a system during the evolution from hadronization to freeze-out. In the symmetric phase a *relative* chemical equilibrium among the particles will be established rapidly, leading to  $\mu_\sigma = \mu_\pi$  and  $\mu_\rho = 2\mu_\pi = \mu_{a_1}$ .

The number of scalar mesons is then given by one third of the total number of pions at the given temperature. This is quite different from the situation encountered in the broken phase, where  $\mu_\sigma = 2\mu_\pi$  and  $\mu_{a_1} = 3\mu_\pi$ . This is mainly due to the appearance of the light  $\sigma$  meson and the drop of the chiral condensate.

This difference in chemical equilibration conditions of pions might lead to the excess of pions at freeze-out. As temperature decreases and the symmetry is broken scalar mesons become heavier and decay into two pions. Also  $a_1$  mesons decay into three pions. The number of observed pions will be given by the number of pions plus contributions from the resonance decay. When we include the scalar and  $a_1$  meson contributions to observed pions, we have 1.4  $\sim$  1.6 times more pions compared to the case when there is no chiral phase transition. This, however, can only be observed, if the chiral transition temperature is not too high  $T_\chi \leq 180$  MeV. Otherwise, pion number changing processes in the broken phase will absorb the excess obtained from the chiral phase transition.

Finally, let us conclude by pointing out that an analysis of the particle abundances measured at SPS-energy heavy ion collisions found an excess of pions by a factor of 1.6 over the expected thermal value [2]. However, a different analysis based on the same data, does not find such an excess of pions [3].

- [1] T. Hatsuda and T. Kunihiro, Prog. Theor. Phys. Suppl. 91 (1987) 284.  
H. A. Weldon, Phys. Lett. B 274(1992) 133.  
R. Pisarski, Phys. Rev. Lett. 76 (1996) 76.
- [2] M. Gazdzicki for the NA35 Collaboration, Nucl. Phys. A590, (1995) 215c.
- [3] P. Braun-Munzinger, J. Stachel, J. Wessels and N. Xu, Phys. Lett. B 365 (1996) 1.

\* LBNL-39391: submitted to Phys. Lett. B